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AN INFLUENCE FUNCTION METHOD FOR PREDICTING STORE AERODYNAMIC C--ETC(U)
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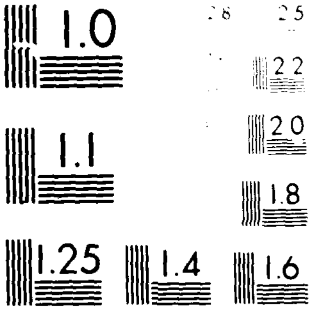
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AN INFLUENCE FUNCTION METHOD FOR PREDICTING STORE AERODYNAMIC CHARACTERISTICS DURING WEAPON SEPARATION

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ABSTRACT

A method has been developed for predicting the forces and moments on a store during weapon separation based on previous wind tunnel data for another store in the same flow field. This new technique uses conventional grid survey store force and moment data and parameter identification analysis to "identify" the local angle-of-attack distribution in proximity to the parent aircraft. Predicted force and moment characteristics for other stores based on this derived angle-of-attack show excellent correlation with supersonic data. The evidence to date indicates that the method will be applicable to virtually all stores at subsonic-supersonic Mach numbers.

INTRODUCTION

Aircraft weapon system effectiveness is dependent on efficient store carriage and satisfactory weapon separation throughout the required flight envelope. Shock-wave formation accompanying supersonic/transonic flight aggravates the already difficult problem of predicting the weapon aerodynamics as it traverses the mutually interfering aircraft weapon flow field. Despite the encouraging progress in theroretical/computational techniques 1,2,3,4, the only comprehensive engineering approach at this time calls for extensive wind tunnel testing of specific aircraft-weapon combinations. Maddox, in Reference 5, notes that wind tunnel results generally show good agreement with flight data but "occasionally" will differ significantly from the full-scale result.

The cost implications of conducting an adequate wind-tunnel test program to demonstrate satisfactory weapon separation are prohibitive. The wide vareity of weapon/store loadings and flight conditions that need to be evaluated cannot be accommodated. A curtailed program, accepting the risk of not uncovering some "unsafe" situations or sacrificing possible lauch envelope extension to "play it safe", is inevitably the result. Past attempts to mitigate this problem by trying to generalize weapon separation data from one store to another, using isolated-store aerodynamic characteristics to account for observed differences, have proven unsatisfactory. It has long been recognized that this simple approach is unacceptable whenever the flow field angularity varies significantly over the store length, making it impossible to define an "effective α" environment.

S. Korn addresses the "effective α" limitation in Reference 6. To overcome this objection he, and others since [3,7], developed the idea of distinguishing between the angle-of-attack experienced by the nose, mid-section, and tail-section of the store. Practical implementation of these concepts depended on using measured or theoretically determined parent aircraft flow field angularity data and estimating nose, mid-section, and tail-section force and moment contributions as a function of their respective local angle-of-attack. If these basic ideas are extended to their logical conclusion one is led quite naturally to consideration of an "Influence Function Method" for predicting store aerodynamic characteristics during weapon separation. The development of just such a method is described below.

TECHNICAL APPROACH

The fundamental assumption underlying the present Influence Function Method (IFM) for predicting store aerodynamic characteristics in a nonuniform flow is that the total store force and moment can be correlated with the angle-of-attack distribution along the store length. Limiting ourselves for the present to a linear correlation and a finite subdivision of the store into N elements, we see (Figure 1) that the store aerodynamic characteristics can be expressed in terms of a corresponding number of normal force (A_i) and pitching moment (B_i) influence coefficients, the zero-lift angle-of-attack (α_o), and the zero-lift pitching moment coefficient, C_{m_o}. The assumed linearity of the analytical model is not intended to suggest any restriction to linear, potential flow aerodynamics - it only implies the existence of a linear input/output relationship similar to the usual practice of approximating aircraft stability characteristics with aerodynamic derivatives obtained by sloping wind-tunnel data. Buoyancy forces are implicitly accounted for in this representation since the causative flowfield pressure gradients (Figure 2) are directly related to flowfield curvature and, hence, the angle-of-attack distribution along the store length.

Practical application of the present IFM technique depends on:

A. Determining the A_i, B_i influence coefficients and α_o, C_{m_o} that characterize the store aerodynamics in a nonuniform flow at the Mach number of interest

B. Using this information and wind-tunnel-measured store force and moment data (obtained in the course of a conventional grid survey in proximity to the parent aircraft) to calculate what the angle-of-attack distribution "had to be" along the traverse to produce the observed force and moment data.

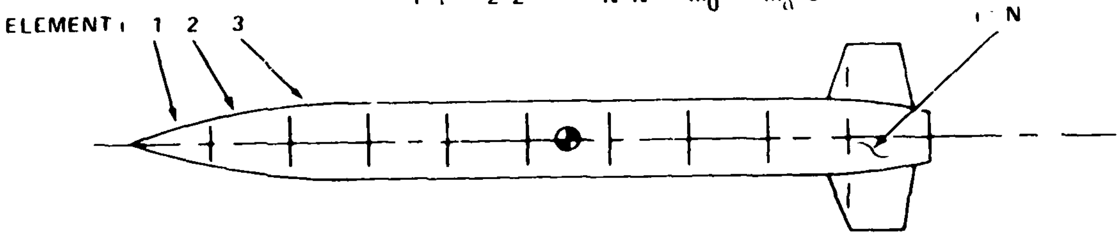
C. Using the derived angle-of-attack and known A_i, B_i, α_o, C_{m_o} characteristics for any "other" store to calculate the forces and moments that this "other" store would experience along the same traverse.

$$C_N = \sum_{i=1}^{N} A_i (\alpha - \alpha_0)_i$$

$$= A_1\alpha_1 + A_2\alpha_2 + \ldots + A_N\alpha_N - C_{N_\alpha}\alpha_0$$

$$C_m = \sum_{i=1}^{N} B_i (\alpha - \alpha_0)_i + C_{m_0}$$

$$= B_1\alpha_1 + B_2\alpha_2 + \ldots B_N\alpha_N + C_{m_0} - C_{m_\alpha}\alpha_0$$



WHERE

A_i	C_N INFLUENCE COEF FOR iTH ELEMENT
α_i	LOCAL α AT iTH ELEMENT
B_i	C_m INFLUENCE COEF FOR iTH ELEMENT
C_{N_α}	ISOLATED STORE NORMAL FORCE SLOPE
C_{m_0}	ISOLATED STORE C_m ZERO LIFT PITCHING MOMENT

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Fig. 1 Mathematical Model for Store Aerodynamics in a Non-Uniform Fl

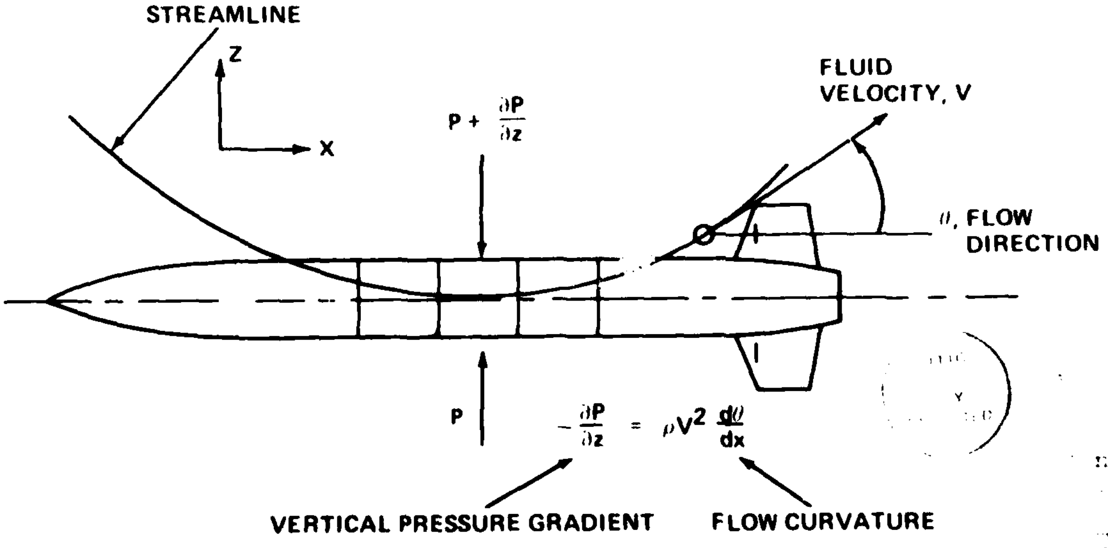

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Fig. 2 Bouyancy Forces in a Curvilinear Flowfield

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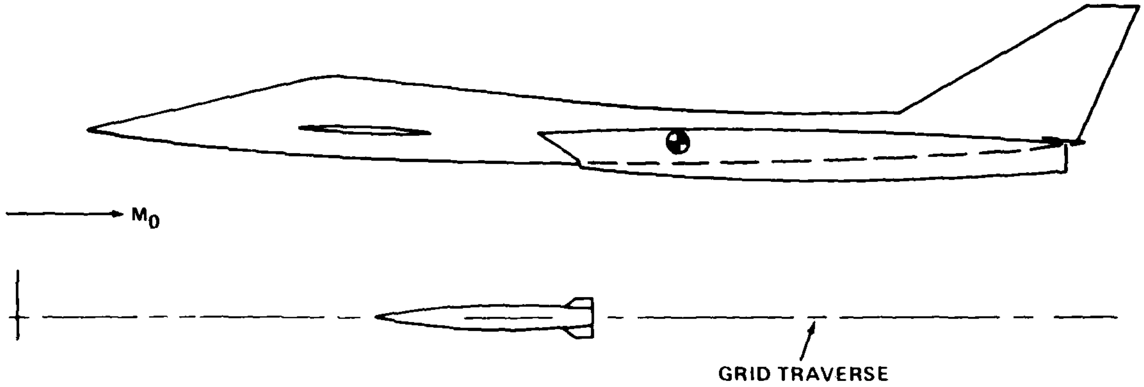

IF INFLUENCE COEFFICIENTS FOR "STORE A" AND "STORE B" ARE KNOWN, THEN:

- **C_m, C_N DATA FROM "STORE A" GRID TRAVERSE CAN BE USED TO CALCULATE THE α DISTRIBUTION ALONG THE TRAVERSE**
- **ABOVE α DISTRIBUTION & KNOWN INFLUENCE COEFFICIENTS FOR "STORE B" ALLOW CALCULATION OF "STORE B" C_m, C_N ALONG SAME TRAVERSE**

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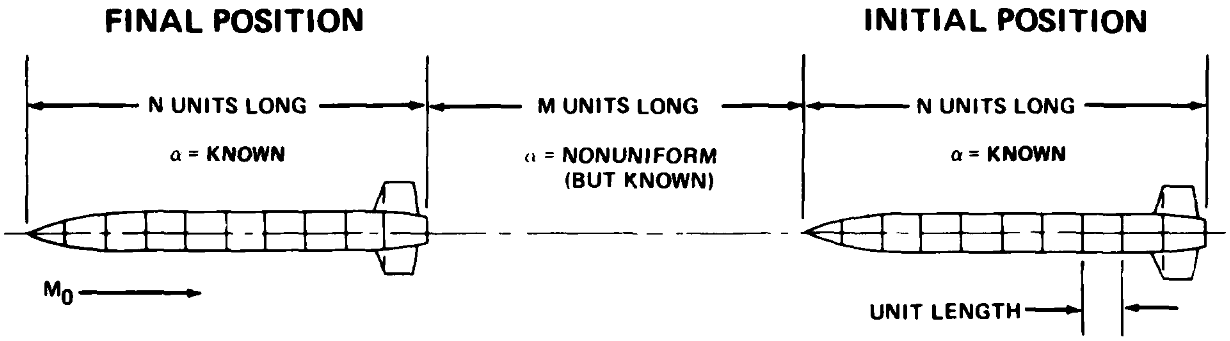
Fig. 3 Applying the Influence Function Method

The overall idea is summarized in Figure 3, where "Store A" designates the original store tested and "Store B" represents the store whose force and moment characteristics are to be predicted. If the foregoing A, B, C process can be successfully implemented it would mean that production grid survey force and moment data for any one store could be used to establish an experimentally derived aircraft "flowfield angularity" data bank for subsequent use in estimating the launch characteristics of other weapons without the need for additional testing. Whether such angularity data must be corrected for flowfield effects induced by the weapon itself (including proximity to the aircraft) has to be answered pragmatically. The indications are that, in most cases, one can ignore these secondary effects and still obtain satisfactory force and moment predictions to within one store diameter of the carriage position. In particularly difficult situations, or where greater accuracy is required, a theoretically determined proximity correction could be applied. The calculation of such a correction would appear to be within the capability of available methods. This subject will be revisited in the closing section of the paper after reviewing some representative data correlations.

The conceptual wind-tunnel test indicated in Figure 4 illustrates how the required store influence coefficients can be determined experimentally (Step A). The sting-mounted store to be "calibrated", i.e., whose A_i, B_i are to be determined, is traversed (downstream to upstream) through a known non-uniform calibration flowfield and the measured store balance force and moment noted. Referring to Figure 4 and assuming that force and moment data are recorded each time the store is indexed forward one store element length, we see that the M+N unit long traverse defines M+N+1 "C_N" equations to determine the N "A_i", $i=1$ to N, influence coefficients and α_o. In the typical equation shown (Figure 4), the measured C_N and α_1, α_2, ...α_N (the calibration flow field α's acting at each store element at that point in the traverse) are the "knowns" and the A_1, A_2, ... A_N, and α_o are the unknowns to be determined.

C_N, C_M WIND TUNNEL DATA ARE RECORDED AS STORE IS INDEXED UPSTREAM FROM ITS INITIAL TO FINAL POSITION



GENERATES 1 + M + N C_N EQUATIONS TO DETERMINE N Ai'S

TYPICAL EQUATION: $C_N = A_1\alpha_1 + A_2\alpha_2 + A_3\alpha_3 + \ldots + A_N\alpha_N - C_{N_\alpha}\alpha_0$

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Fig. 4 Experimental Determination of Store/Weapon Influence Coefficients

The fact that this system is overdetermined, i.e., that we have more equations than unknowns, can be used to advantage as it allows us to construct a "best" estimate for the A_i's that, on-average, best satisfies all the data. Various mathematical procedures, often referred to as parameter identication techniques, are available to construct such "optimal" estimates given a redundant set of noisy data. We have found that a simple least squares estimation technique works extremely well for the A_i and B_i determination from experimental data.

The choice of calibration flow field is only limited by the requirement that the flowfield angularity be accurately known and sufficiently nonuniform to establish a substantial angle-of-attack variation over the store length. AFWAL/Grumman supersonic wind-tunnel test experience at AEDC and the WPAFB Trisonic Gasdynamics Test Facility show that accurate store calibrations can be accomplished using a simple 2-D oblique shock flowfield generated by a flat plate at incidence. Satisfactory store calibration requires that the flowfield angularity be known to within a few tenths of a degree. This requirement virtually eliminates the use of yaw head angularity data. While this may appear to be a disadvantage, it is not, since there is no need to measure the calibration flowfield angularity - it can be predicted theoretically with sufficient accuracy if the flowfield is selected appropriately, i.e., wedge flows and a variety of axisymmetric forebody flow-fields.

Figures 5 and 6 show the experimentally derived normal force (A_i) and pitching moment (B_i) influence coefficient distribution for a representative winged supersonic standoff weapon at M=1.89. In this case the store was divided into 16 elements and the respective A_i, B_i for each element determined from a least squares analysis of the CN, C_m data taken during a store calibration through a four-degree oblique shock wave. It should be noted that the A_i distribution in Figure 5 does not represent the weapon longitudinal loading distribution - it represents the total normal force that the store would experience if a unit α were applied to the ith store element and α were zero for all other elements.

Maximum span for this delta-winged weapon occurs at missile station 132, which accounts for the large positive A_i (large positive C_N response) and large negative B_i (large negative C_m response) at that location. The negative A_i's over the forebody are due to buoyancy effects and are real. Note the twin negative peaks in the B_i distribution (Figure 6), which coincide with the wing trailing edge station and the tail location. The intervening valley is due to the gap between the wing and tail which was sensed in the original calibration data. Mach wave inclination, wake effects and data fairing account for the non-zero A_i, B_i values noted slightly upstream and downstream of the nose and tail stations.

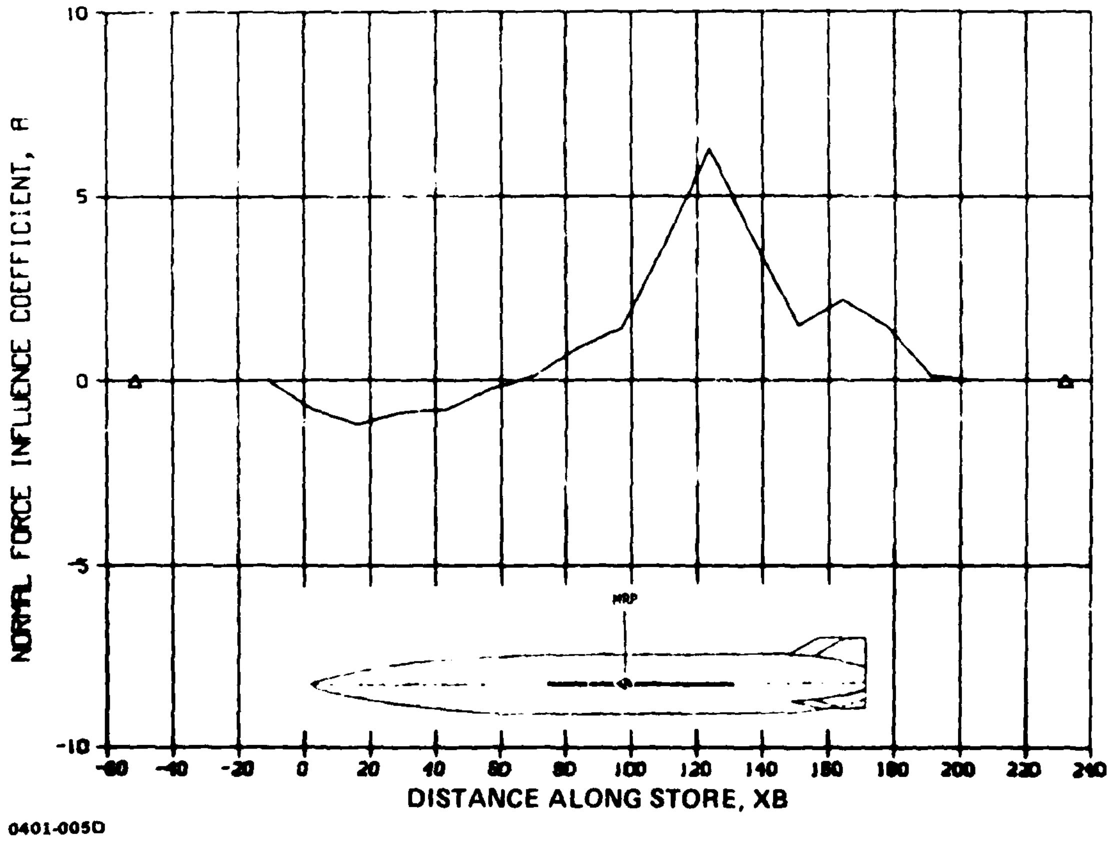

Fig. 5 Planar Wing Weapon Normal Force Influence Coefficient Distribution, M = 1.89

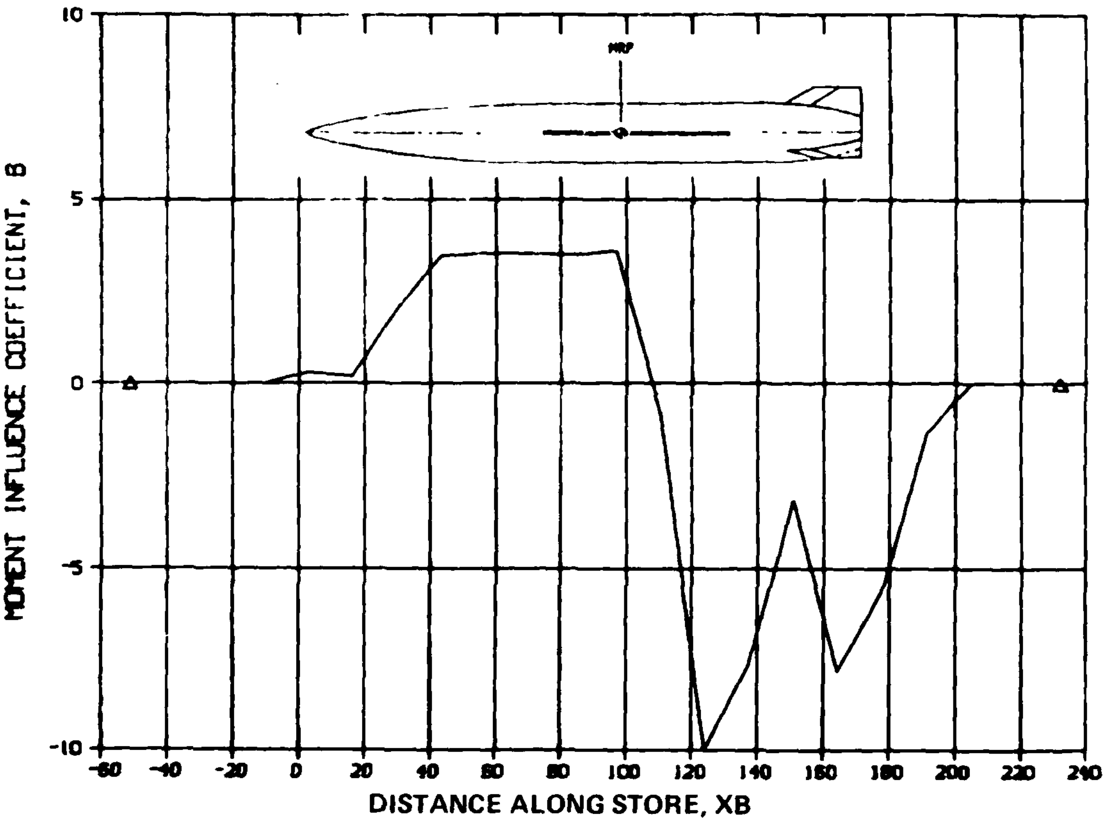

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Fig. 6 Planar Wing Weapon Pitching Moment Influence Coefficient Distribution, M = 1.89

All experience and evidence to date indicate that satisfactory experimental calibrations can be accomplished within the usual data accuracy standards associated with grid survey force and moment data. This observation is directly supported by wind-tunnel data for M = 1.5 to 2.3, and there is no reason to expect contrary results at subsonic speeds.

Proceeding to the next phase in the application of the IFM technique to weapon separation, we now show how conventional grid survey force and moment data, taken in proximity to the parent aircraft, can be used to calculate the angle-of-attack distribution along the same traverse (Step B). The problem is illustrated in Figure 7. The sting-mounted and previously calibrated store is assumed to traverse upstream, one store element length at a time, while the store balance data are recorded. This process generates M+N+1 "C_N" and a like number of "C_m" equations, or 2M+2N+2 equations that define the M+2N unknown α's spanning the nose-to-tail extremeties of this traverse. A redundant set of equations is obtained provided the store is traversed at least one store length forward.

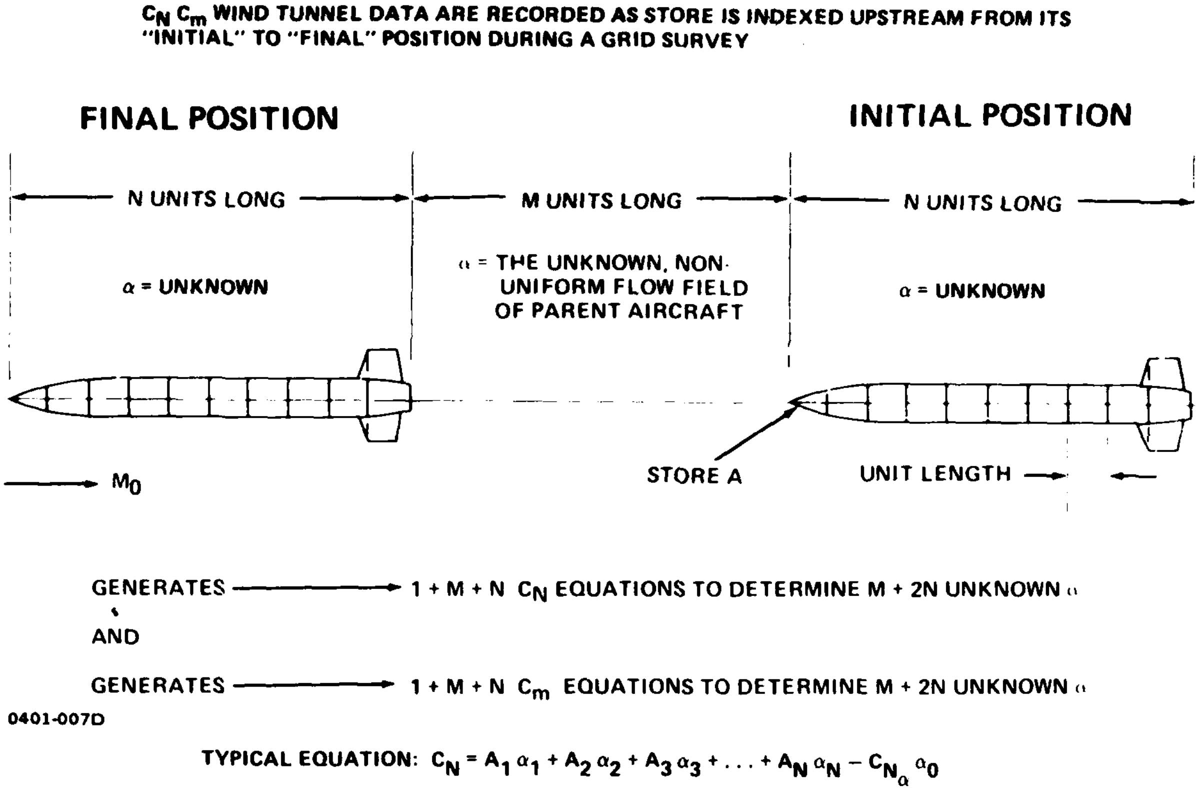

Fig. 7 Determination of Non-Uniform Flowfield Angle-of-Attack Distribution from Grid Survey Force and Moment Data

Figure 8 shows a typical least square estimate of the α distribution along a traverse in proximity to the parent aircraft. These particular results are based on conventional grid survey force and moment data taken at AEDC for a traverse location 166 inches (full scale) below the FRL of Grumman's 1/27-scale Supersonic Tactical Aircraft (STAC) wind-tunnel model. As would be expected, each of the peaks and crests in this predicted α distribution is related to some prominant configuration feature such as the nose, canard, inlet, or wing.

The final "Step C" in the IFM prediction process requires nothing more than taking the derived angle-of-attack distribution in proximity to the aircraft (as determined in Step B) and the influence coefficient data for any "other" previously calibrated store to construct a normal force/pitching moment prediction for this "other" store. Figure 9 illustrates the conceptual process. In this case, "Store B" represents the store whose force and moment characteristics along the indicated traverse are to be estimated. As indicated in the representative equations shown, C_N and C_m can be calculated by direct substitution for the known A_i, B_i, α_o, C_{m_o} and the known α_i along the traverse.

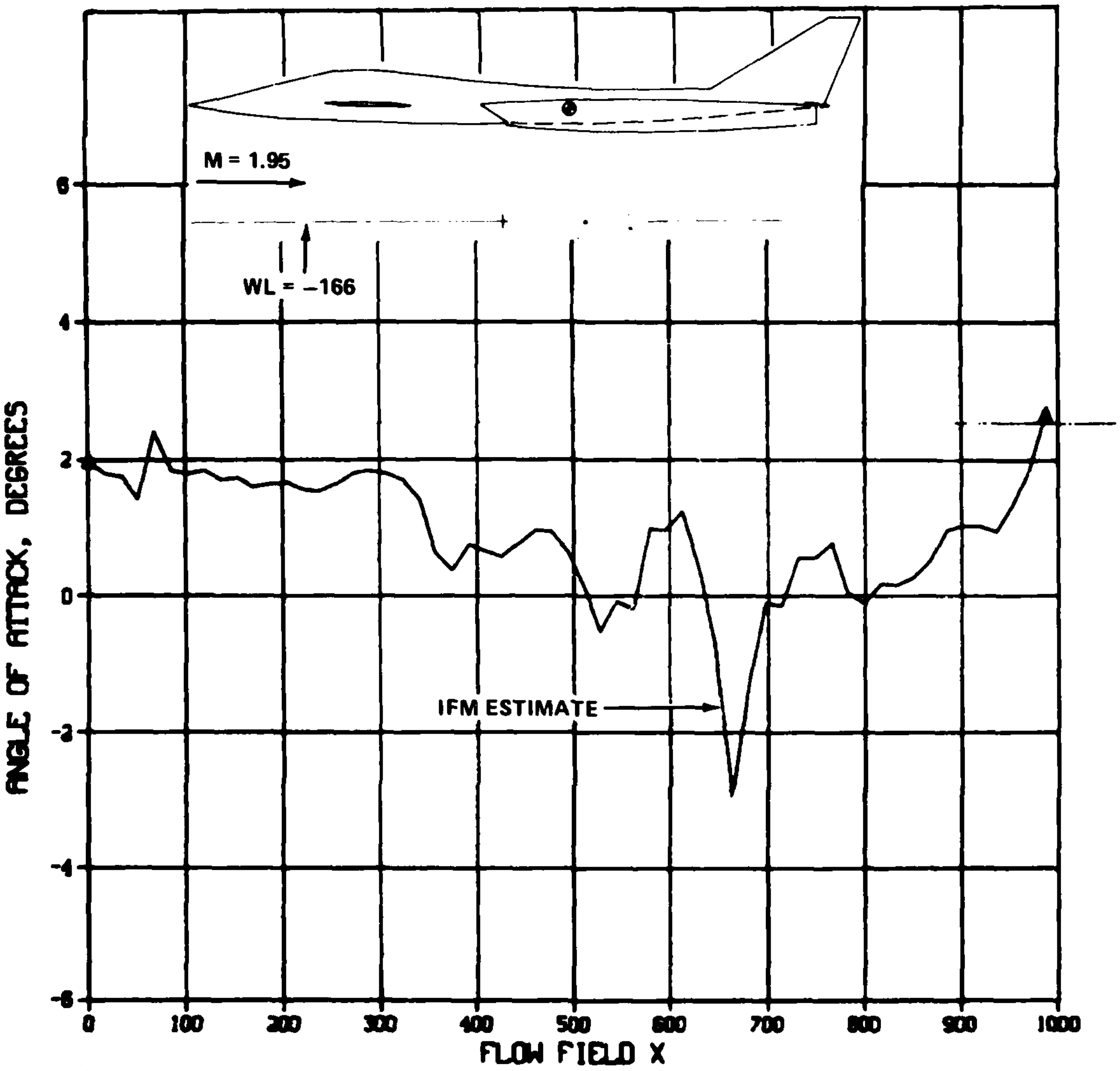

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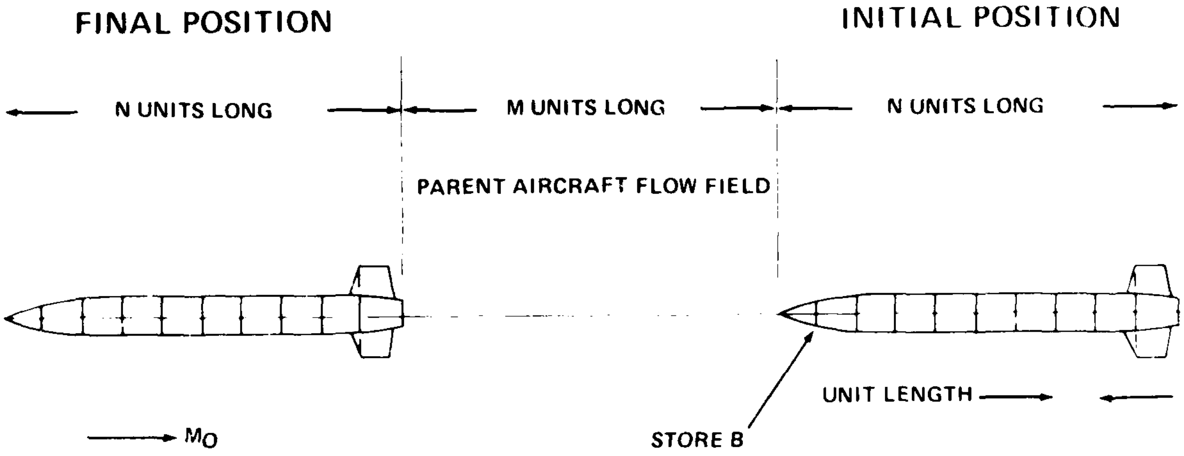
Fig. 8 "Estimated" Local Angle-of-Attack Distribution Along WL-166 Traverse in Proximity to Grumman STAC

In principle, the A, B, C process outlined above shows how grid survey force and moment data for one store can be used to estimate the force and moment characteristics of another store in the same flowfield. The essential requirement in this predictive process is that both stores must have been previously "calibrated" at the Mach number of interest.

In the interests of clarity we have consistently described the mechanics of the present IFM in terms of an experimental/operational approach to emphasize that the concepts can be so implemented. In many cases, however, it may prove more economical to calibrate a particular store using theoretical/computational techniques to duplicate the experimental process described herein. AFWAL/Grumman experience to date shows excellent correla-

CONCEPTUALLY, "STORE B" IS INDEXED UPSTREAM FROM ITS "INITIAL" TO "FINAL" POSITION ALONG TRAVERSE WHERE α DISTRIBUTION IS KNOWN



IF "STORE B" INFLUENCE COEFFICIENTS ARE KNOWN, THEN "STORE B" C_N, C_m CAN BE CALCULATED DIRECTLY, I.E.,

$$C_N = \sum_{i=1}^{N} A_i \alpha_i - C_{N_\alpha} \alpha_0$$

$$C_m = \sum_{i=1}^{N} B_i \alpha_i + C_{mO} - C_{m_\alpha} \alpha_0$$

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Fig. 9 Predicting the Aerodynamic Force and Moment on a Calibrated Store

tion between the experimentally derived and theoretically calculated influence coefficients. The outlook for continued success in this area is certainly promising.

Another interesting "wrinkle" is the use of "secondary" experimental calibrations to calibrate a store without the necessity of setting up a dedicated wind-tunnel test. This involves traversing the "uncalibrated" store along a conventional grid survey traverse that has been previously surveyed by a "calibrated" store. For example, the estimated α distribution along the -166 inch waterline shown in Figure 8 (established using the calibrated planar wing weapon) and measured grid C_N, C_m data for our hypothetical "uncalibrated" store along this same traverse would suffice to calibrate that store per the earlier discussion surrounding Figure 4. Experience indicates that such secondary calibrations are very nearly as accurate as the primary calibration data obtained from dedicated testing.

EXPERIMENTAL RESULTS

Representative IFM prediction - wind tunnel data correlations are included herein. The M = 1.95 data were taken in proximity to a 1/27-scale model of Grumman's STAC configuration (Figure 10). In this case, the planar wing weapon (Figure 11) grid survey data were used to estimate the air-to-ground weapon (Figure 11) data along the WL = -166, BL = 0 and WL = -76, BL = 54 traverses indicated in Figure 12. Both stores were "calibrated" in the WPAFB Trisonic Gasdynamics Test Facility using a four-degree oblique shock calibration flowfield.

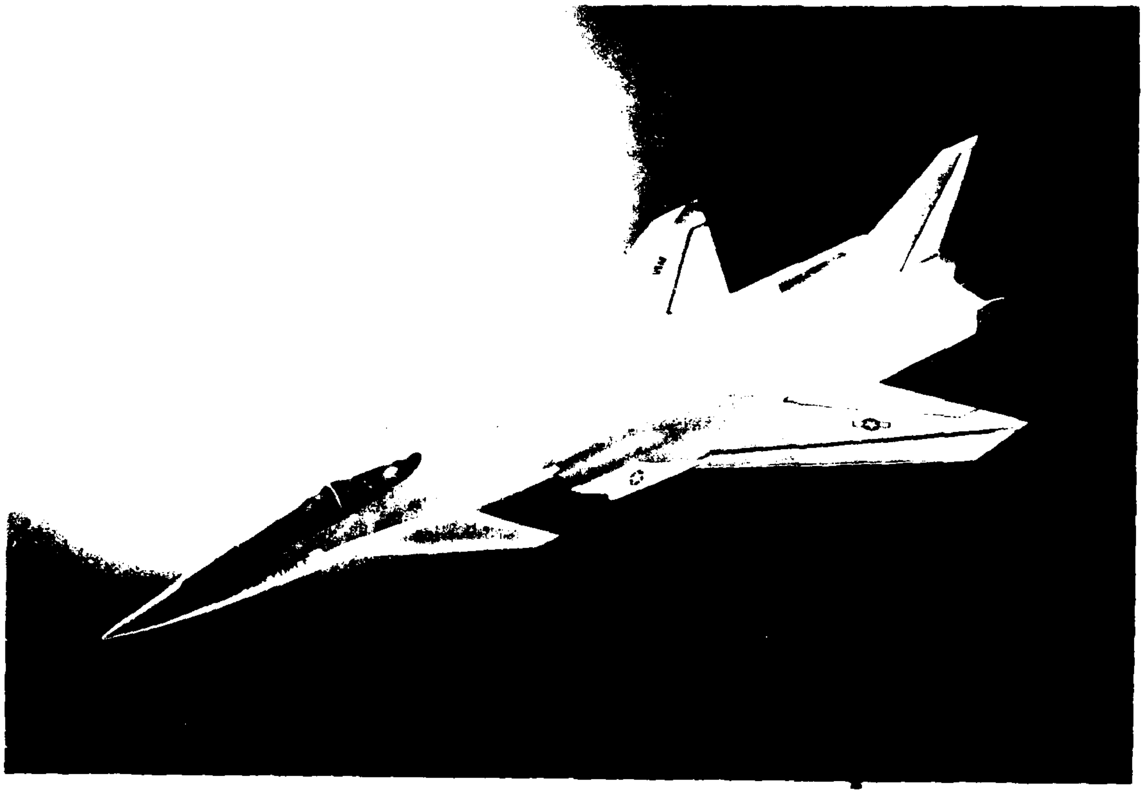

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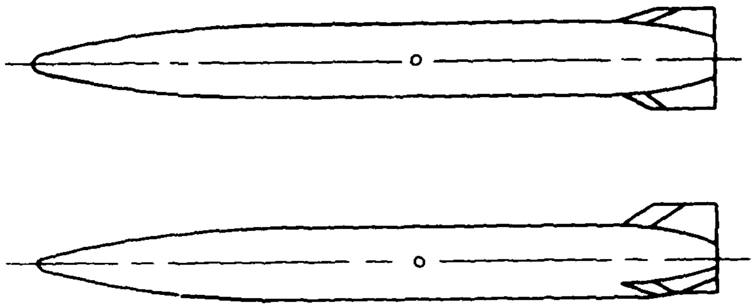
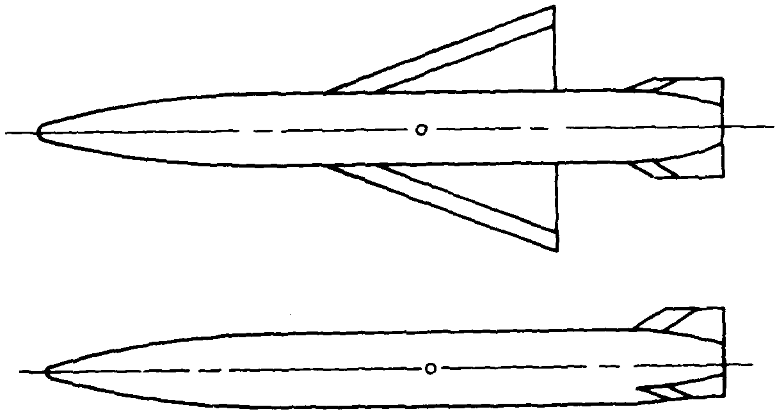
Fig. 10 Grumman Supersonic Tactical Aircraft Configuration (STAC)

The IFM predicted C_N, C_m for the air-to-ground store show good agreement with the wind-tunnel data at WL = -166 (Figures 13 and 14). The theory-data discrepancy upstream of station 100 and downstream of station 800 is characteristic of IFM predictions near the "ends" of a traverse since the α's in



A. AIR-TO-GROUND (A-G) MODEL



B. PLANAR WING WEAPON (PWW) MODEL

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Fig. 11 1/27-Scale Grumman Store Models

this region are not accurately defined by the least squares identification process. IFM predictions at WL = -76, BL = 54 also show good agreement with air-to-ground test data (Figures 15 and 16). In this case, the weapon traverse comes within one store diameter of the model nacelle.

The foregoing IFM predictions were based on parent aircraft flow-field angularity distributions determined from grid survey store force and moment data. None of the angularity estimates were corrected for secondary flow-field effects due to the weapon itself.

Judging from weapon/flat plate proximity data from the WPAFB Trisonic Facility at M=1.5 and 1.9, it appears that the weapon-induced effect is less than 20% of the total store force and moment to within one diameter of the carriage position. In exceptional cases, or where greater prediction accuracy is required, a theoretical proximity correction could be applied. The accuracy level demanded of this correction would be modest, e.g., a 25% error in a theoretically calculated correction would result in only ~5% error in the total store force and moment estimate. The calculation of such

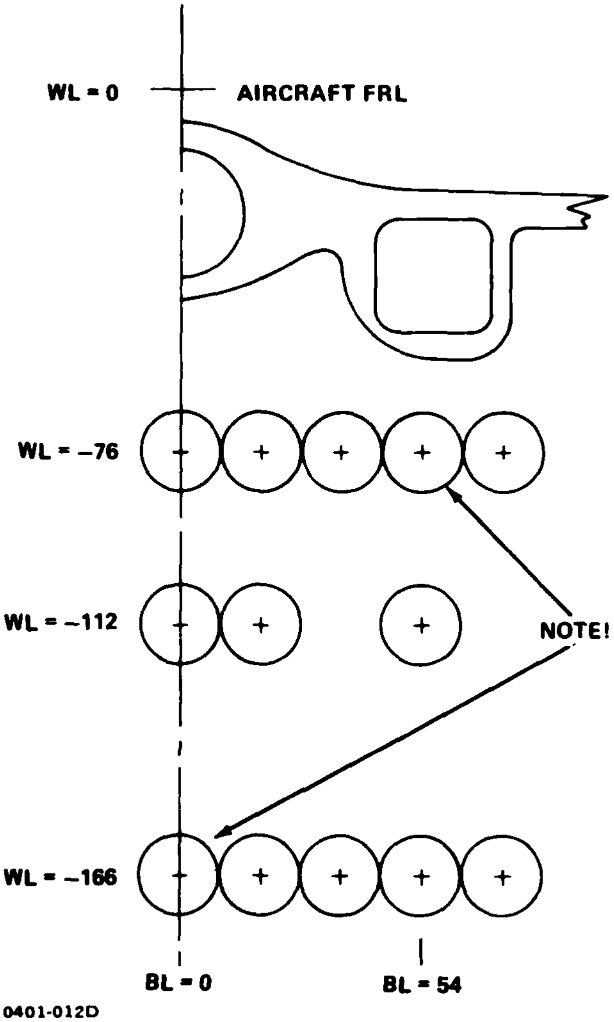

Fig. 12 Cross-Sectional View of 1/27-Scale STAC Grid Survey at AEDC

a correction is much less demanding or difficult than attempting to calculate the total aircraft flowfield since only the reflection effect need be modeled. As noted in Reference 1, the volume effect of the store nose is probably the only induced interference effect that may need to be accounted for.

The present IFM has been successfully applied to a significant number of supersonic grid survey data sets; those shown here are representative. Grumman is presently under contract to AFWAL/FIMM to finalize the IFM technique for supersonic applications, develop user oriented codes, and address specific issues related to future subsonic/transonic applications.

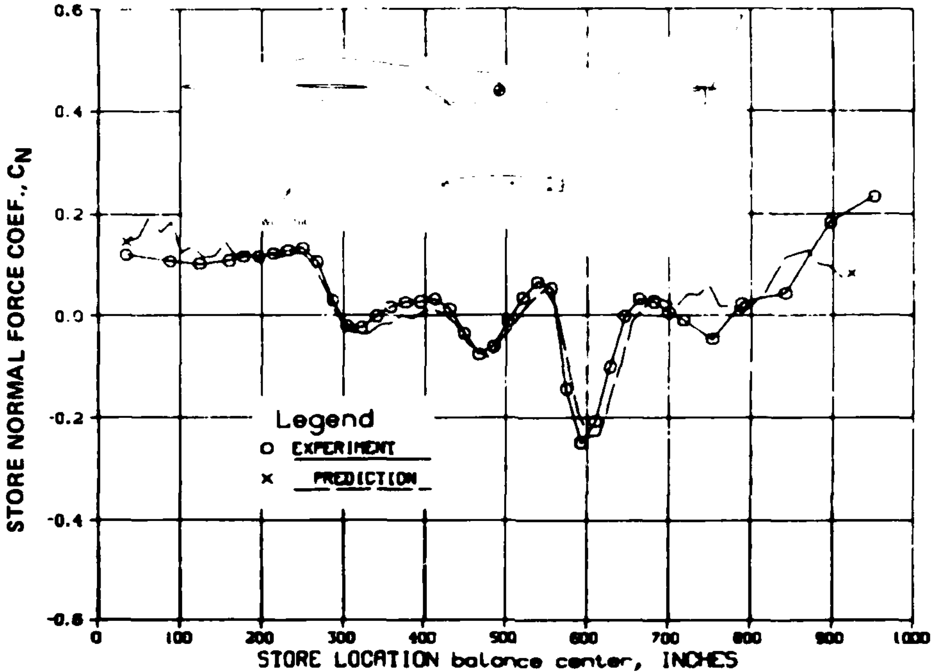

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Fig. 13 Air-To Ground Weapon IFM Normal Force Prediction Compared with Wind-Tunnel Data, M = 1.95

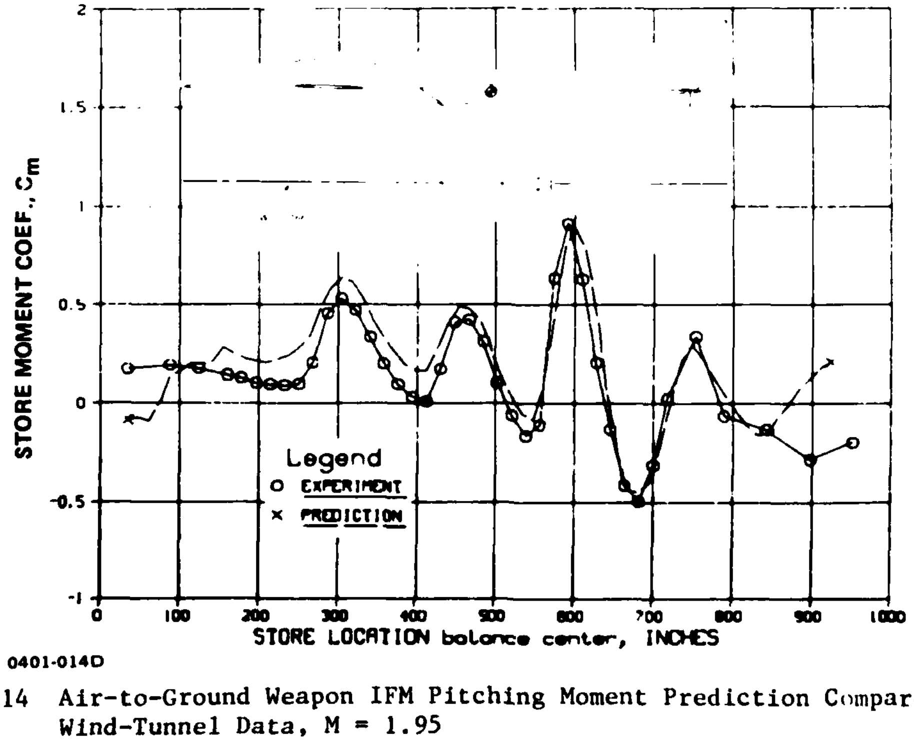

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Fig. 14 Air-to-Ground Weapon IFM Pitching Moment Prediction Compared with Wind-Tunnel Data, M = 1.95

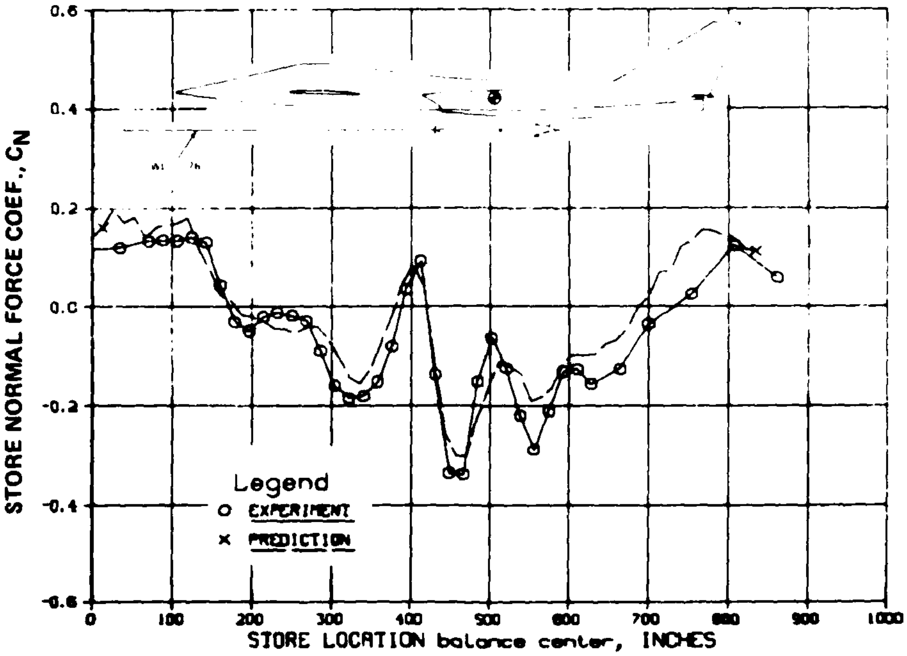

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Fig. 15 Air-to-Ground Weapon IFM Normal Force Prediction Compared with Wind-Tunnel Data, M = 1.95

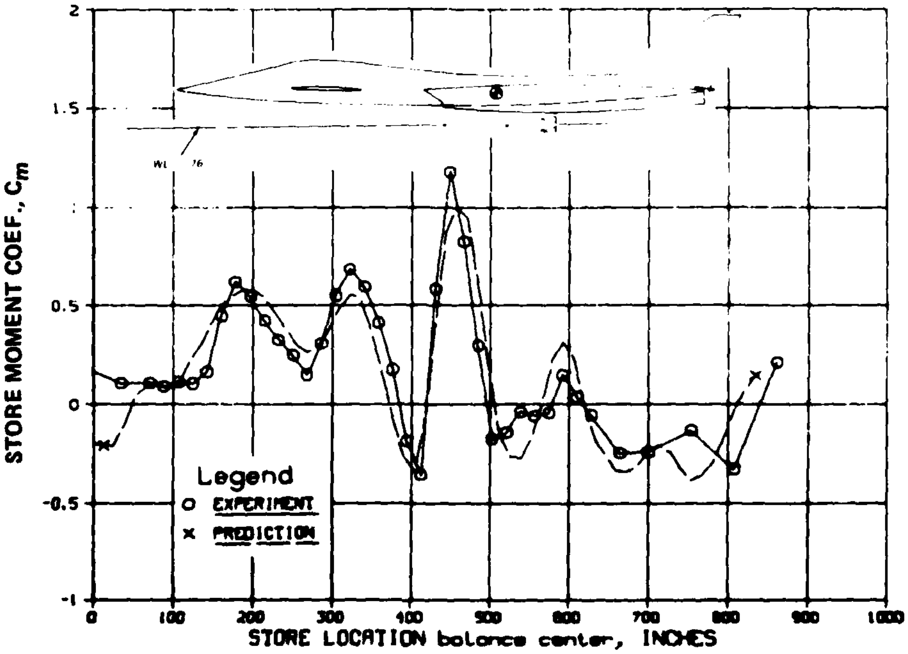

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Fig. 16 Air-to-Ground Weapon IFM Pitching Moment Prediction Compared with Wind Tunnel Data, M = 1.95

CONCLUSION

A method has been developed for predicting the aerodynamic forces and moments acting on a store during weapon separation based on previous wind-tunnel data for another store in the same flowfield. Predicted forces and moments based on this Influence Function Method (IFM) show excellent correlation with supersonic test data. This work is currently being extended to the subsonic/transonic speed range and should provide a comprehensive and unified approach to predicting store separation aerodynamics. Continued development of this technique is expected to result in substantial improvements in the cost-effectiveness of future weapon separation test programs.

The present IFM technique can be implemented as a strictly experimental/operational technique for the wind-tunnel prediction of weapon separation characteristics. In many cases, however, it may prove advantageous to employ theoretical/computational techniques to implement selected elements of the prediction process. The best "mix" of experimental/theoretical implementation will be dictated by cost/capability considerations.

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